Geophysical Research Abstracts
Vol. 18, EGU2016-9629, 2016
EGU General Assembly 2016

Laboratory Observations of the Spectrum of Fault Slip Behaviors

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Slow earthquakes, tectonic fault tremor, and low frequency earthquakes represent an important enigma in earthquake science. In the standard model of earthquake physics elastic energy is released catastrophically as the fault weakens and dynamic rupture expands at speeds measured in km/s. The spectral content of the resulting seismic waves is understood in terms of a source model based on elastodynamic rupture propagation. However, faults also fail in slow earthquakes and there is no such understanding of rupture dynamics, seismic spectra, or source scaling relations in these cases. The mechanics of slow earthquakes are poorly understood in part because there are few systematic laboratory observations that can be used to identify the underlying mechanics. Here, I summarize and discuss results from numerical models of slow slip using rate/state friction laws and recent lab studies showing slow slip and the full spectrum of stick-slip behaviors. Early lab studies saw slow slip during frictional sliding or in association with dehydration or ductile flow; however, they did not include systematic measurements that could be used to isolate the underlying mechanics. Numerical studies based on rate/state friction also document slow slip and chaotic forms of stick-slip, however they require special conditions including two state variable frictional behavior. Recent lab work sheds new light on slow earthquakes by showing: 1) that repetitive, slow stick-slip can occur if the fault friction-velocity relation becomes positive during slip acceleration, and 2) that slow slip and the full spectrum of fault slip modes can occur if loading stiffness k matches the fault zone critical rheologic stiffness kc given by the frictional weakening rate and the critical frictional distance. These data show that the key control parameter for stress drop, slip speed, and slip duration is the non dimensional stiffness k' = k/kc, with the spectrum of fast to slow slip mode occurring in a narrow range around k'=1. I discuss: 1) implications of these results for stress drop of slow earthquakes and the spectrum of fault slip behaviors and 2) fault zone stiffness in the source region of slow earthquakes.